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CONTINUATION-IN-PART PATENT APPLICATION

DEVICE AND METHOD FOR TRACKING CONDITIONS IN AN ASSAY

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DEVICE AND METHOD FOR TRACKING CONDITIONS IN AN ASSAY

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation-in-part of U.S. Patent Application Serial No. 09/751,231, filed December 28, 2000, the disclosure of which is incorporated by reference herein.

TECHNICAL FIELD

This invention relates generally to assay condition tracking. More particularly, the invention relates to devices comprising a substrate having surface-attached molecular probes to carry out an assay and having integrated indicators responsive to environmental conditions associated with the assay.

BACKGROUND

The formation of high-density biomolecular arrays, e.g., oligonucleotidic or polynucleotidic arrays, is well known in the art. For example, U.S. Patent No. 5,744,305 to Fodor et al. describes arrays of oligonucleotides and polynucleotides. The arrays are described as consisting of a plurality of different oligonucleotides attached to a surface of a planar non-porous solid support at a density exceeding 400 different oligonucleotides/cm^2. This patent discloses that photolithographic techniques associated with semiconductor processing may be employed in order to form arrays of such high density.

Arrays may be readily appreciated as additionally being efficient screening tools. Miniaturization of arrays saves synthetic reagents and conserves sample, a useful improvement in both biological and non-biological contexts. See, for example, U.S. Patent Nos. 5,700,637 and 6,054,270 to Southern et al., which describe a method for chemically synthesizing a high density array of oligonucleotides of chosen monomeric

unit length within discrete cells or regions of a support material, wherein the method employs an inkjet printer to deposit individual monomers on the support. So far, however, miniaturized arrays have been costly to make and contain significant amounts of undesired products at sites where a desired product is made. Array density is also limited with the Southern "spotting" method as well as the Fodor et al. photolithographic technique.

The use of focused acoustic energy to form high density arrays has been found to overcome the aforementioned disadvantages of conventional array preparation methodologies. Preparation of arrays using focused acoustic energy is described in detail in U.S. Patent Applications Serial Nos. 09/699,996 and 09/964,212 ("Acoustic Ejection of Fluids from a Plurality of Reservoirs"), inventors Ellson, Foote and Mutz, filed on September 25, 2000 and September 25, 2001, respectively, and assigned to Picoliter Inc. (Mountain View, California). The arrays may be formed on permeable or impermeable support surfaces. See U.S. Patent Application Serial No. 09/964,205 ("Method and Apparatus for the Generation of High Density Arrays on Permeable Surfaces"), inventors Ellson, Mutz and Foote, filed on September 25, 2001 and assigned to Picoliter Inc. As described in the aforementioned patent applications, focused acoustic energy may be used to prepare arrays of a variety of biological and nonbiological materials, including nucleotidic, peptidic, metallic, ceramic and amorphous materials. See also U.S. Patent Applications Serial Nos.: 09/963,173 ("Focused Acoustic Energy in the Preparation of Peptide Arrays"), inventors Mutz and Ellson, filed on September 25, 2001 and assigned to Picoliter Inc.; 09/962,731 ("Arrays of Partially Nonhybridizing Oligonucleotides and Preparation Thereof Using Focused Acoustic Energy"), inventor Ellson, filed on September 24, 2001 and assigned to Picoliter Inc.; and 09/962,730 ("Focused Acoustic Energy Method and Device for Generating Droplets of Immiscible Fluids"), inventors Ellson, Mutz and Foote, filed on September 24, 2001 and assigned to Picoliter Inc. The arrays may be combinatorial libraries, comprised of a plurality of different chemical or biological moieties present on the surface of a substrate. Combinatorial libraries offer utility in a variety of applications, for example in the high-throughput screening of potentially useful compositions of matter. See U.S. Patent Application Serial No.

09/964,215 ("Focused Acoustic Ejection in the Preparation and Screening of Combinatorial Libraries"), inventors Mutz and Ellson, filed September 25, 2001 and assigned to Picoliter Inc.

High-throughput assays, such as those used during oligonucleotide hybridization experiments, often take place on an array of test sites on an assay substrate. Assay substrates may, for example take the form of glass plates, microscope slides, or microtiter well plates, and test sites may be formed as features on such substrate surfaces. Many arrays are formed that have large feature-to-feature and array-to-array variations, and such variations adversely affect the reproducibility of experimental conditions and results. The variation in the assay substrate consequently increases the difficulty in comparing results from experiment to experiment, in effect increasing the noise-to-signal ratio in these experiments.

In order to ensure the accuracy of these experiments, a control sample is usually used in conjunction with a test sample. The control sample may be used to determine the degree of feature-to-feature and array-to-array variation. In other words, conducting the experiment with the control sample serves to calibrate the assay results. This is disadvantageous for a number of reasons, one of which being that the control sample itself may be a source of variability. That is, if there is excessive variation in the control sample, the control sample is no longer useful as a calibration tool. Moreover, single-feature controls typically indicate merely whether, for example, a hybridization event has occurred. If no hybridization event has occurred, such controls do not provide additional information to assess why hybridization did not occur or to guide the user directly to a more successful experiment.

For example, one widely used method for managing variability in arrays involves applying two samples, a control and a test sample, simultaneously to the same array. By labeling each sample with a different tag, such as different colors of fluorescent markers, the amount of binding of each tag can be measured independently at each site. Such labeling with different markers has been described, e.g., in U.S. Patent Nos. 5,770,358 to Dower et al., 5,800,992 to Fodor et al., and 5,830,645 to Pinkel et al. By comparing the signal of the test sample interaction with a test site, and the signal of the control sample

interaction with the same test site, a source of variability is eliminated. However, using different tags on the test and control samples introduces a new source of variability. The relative chemical activity of the test and control samples may be altered, which in turn changes the reaction rate of the two samples with the test site. As a result, another experiment may be required to determine the effect of using different tags. This can be carried out by repeating the experiment using the control and the test samples labeled with switched tags. However, repeating the experiment may reintroduce array-to-array and feature-to-feature variability. Thus, it becomes extremely important to ensure that the repeated experiment is conducted in a substantially identical manner to the first experiment.

The above example illustrates the need to address feature-to-feature and array-to-array variability and the need to ensure the assay is performed under uniform conditions. It is, however, important to note that optimal assay analysis should effectively decouple the array-to-array and feature-to-feature variations and the conditions under which the assay was performed with the array. As the array-forming technology becomes more effective in generating reproducible arrays, the contribution to variation from the assay procedure grows in importance. Thus, in order to ensure that an experiment is repeated with accuracy, it is important to have an accurate record of the previous experimental conditions, irrespective of array-to-array or feature-to-feature variations. In addition, it may be helpful to have an accurate record of the conditions in which arrays are formed.

There are a number of patents that describe integrated devices containing both surface-bound chemical moieties and related information. See, e.g., U.S. Patent Nos. 6,030,581 to Virtanen, 5,872,214 to Nova et al., and 5,935,786 to Reber et al. In another example, U.S. Patent Applications Serial Nos. 09/712,818 and 09/993,353, filed on November 13, 2000 and November 13, 2001, respectively ("Integrated Device with Surface-Attached Molecular Moieties and Related Machine-Readable Information"), inventors Ellson, Foote, and Mutz, assigned to Picoliter Inc. (Mountain View, California), describes substrates having a surface adapted for attachment with a plurality of molecular moieties and containing related machine-readable information that facilitates formation and/or use of those moieties, e.g., arrays. While information relating

to assay conditions may be contained in these devices, assay conditions must be separately monitored and then converted into information in the devices. This poses a problem, particularly where it is desirable to perform assays using different equipment, at different locations, or at widely separated times.

Thus, there is a need in the art for improved devices comprising a substrate having a plurality of surface-attached moieties and an integrated indicator that exhibits a response to a condition wherein the response is detectable after removing the indicator from the condition, thereby providing a record of the condition. The condition may relate to the execution of an assay or to the formation of a device to carry out an assay.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide devices and methods that overcome the above-mentioned disadvantages of the prior art. In one embodiment, the invention provides a device comprising a substrate having a plurality of different molecular probes attached to a surface thereof and an integrated indicator that exhibits a response when exposed to a condition to which the substrate may be exposed. Each different molecular probe is selected to interact with a corresponding target. The probes preferably interact with different targets but in some cases may interact with the same target with differing degrees of affinity. The indicator response is detectable after removing the indicator from the condition. The indicator response to the condition is typically detectable for at least one minute after removing the indicator from the condition and is, preferably, substantially permanently detectable.

In another embodiment, the invention provides a device comprising a substrate having a plurality of molecular probes attached to a surface thereof and a plurality of different integrated indicators. Each indicator is selected to exhibit a response when exposed to one of a plurality of conditions to which the substrate may be exposed. The molecular probes are selected to interact with corresponding targets. Again, the indicator response is detectable after removing the indicator from the condition. In some cases, the molecular probes are selected to interact with corresponding targets when exposed to at least one of the plurality of conditions. In other cases, molecular probes are selected to

interact with corresponding targets when exposed to all of the conditions. Furthermore, molecular probes may be selected to interact with corresponding targets when exposed to all of the conditions simultaneously.

The inventive devices are typically used for biomolecular assays. Thus, the probes are typically biomolecular. More specifically, the probes are ordinarily nucleotidic or peptidic. Often, the probes are arranged in a high-density array on the substrate surface, and such an array may comprise at least about 1,000,000 probes per square centimeter of substrate surface. The probes may interact with targets of various types. For example, the targets may represent portions of a single molecule or portions of a single cell. In the case where the probes are nucleotidic, it is preferred that the integrated indicator also comprises a nucleotidic material.

Thus, in still another embodiment, the invention provides a device comprising a substrate having a plurality of nucleotidic molecular probes attached to a surface thereof and an integrated indicator that exhibits a response when exposed to a condition to which the substrate may be exposed. In this embodiment, the nucleotidic molecular probes are selected to interact with corresponding targets. As in the case of the above embodiments, the indicator response in this embodiment is also detectable after removing the indicator from the condition. Preferably, the condition represents a hybridization condition between the probes and targets.

For any of the above-described embodiments, the indicator may exhibit a response to various conditions such as an environmental condition that allows for or prohibits target-probe interaction. These conditions include, for example, temperature, chemical composition, and chemical concentration. Although the indicator response may be magnetically and/or electrically detectable, the response is preferably optically detectable and optimally fluorescently detectable. Optical detection can involve, for example, detection of chemiluminescence as will be seen with chemiluminescent dyes, and fluorescence detection, including detection of fluorescence emission or quenching, using fluorescent dyes or fluorescent dye-fluorescence quencher pairs, respectively.

The invention also provides various devices and methods for assaying a sample using the inventive devices as described above. The assay is carried out by first exposing

any of the above described devices to an assay condition, by contacting a sample with the probes attached to the substrate surface of the device. Depending on whether the indicator exhibits a response, the assay further involves detecting for probe-target interactions. That is, the presence or the absence of an indicator response serves as a quality control measure for the assay.

In a further embodiment, the invention provides a device comprising a substrate having a surface adapted for attachment to a plurality of molecular moieties and an integrated indicator that exhibits a response when exposed to a condition. As is the case with the above-described embodiments, the indicator response is detectable after removing the indicator from the condition. This embodiment may serve as a precursor to the above-described embodiment. Accordingly, the indicator for this embodiment may exhibit a response to a condition that is or is not suitable for attaching the plurality of molecular moieties to the substrate surface. Also provided are an apparatus and method for attaching molecular moieties to the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A, 1B, and 1C, collectively referred to as FIG. 1, schematically illustrate a device of the present invention comprising a substrate in the form of a single disk having molecular probes and an integrated indicator attached to a top surface of the disk. FIG. 1A shows the top view of the disk. FIG. 1B illustrates a cross-sectional view of the device along dotted line A. FIG. 1C illustrate a bottom view of the disk.

FIGS. 2A, 2B, 2C, and 2D, collectively referred to as FIG. 2, illustrate in schematic view another version of the inventive device wherein the substrate comprises a cartridge containing a magnetic disk and having an exterior surface formed by a well plate having an array of integrated indicators thereon and molecular moieties attached to an interior surface of each well of the well plate. FIG. 2A shows a top view of the cartridge. FIG. 2B illustrates the cartridge of FIG. 2A in cross-sectional view along dotted line B. FIG. 2C illustrates the cross-sectional view of the cartridge of FIG. 2A along dotted line C. FIG. 2D illustrates the bottom view of the cartridge.

FIGS. 3A, 3B, and 3C, collectively referred to as FIG. 3, schematically illustrate in simplified cross-sectional view another version of the inventive device in the form of a slide having two opposing surfaces. FIG. 3A shows the top view of the slide having probes and integrated indicators attached thereto, and FIG. 3B illustrates a cross-sectional view of the slide of FIG. 3A along dotted line E. FIG. 3C shows the bottom view of the slide having an optional memory chip.

FIG. 4A, 4B, 4C, and 4D, collectively referred to as FIG. 4, schematically illustrate in simplified cross-sectional view a method for carrying out an assay using the inventive device. In FIG. 4A, a device is shown having a construction similar to that illustrated in FIG. 3. FIG. 4B illustrates the loading of the device into a hybridization chamber wherein a fluid sample comes into contact with the probes. FIG. 4C illustrates the case wherein some probes are shown hybridized with labeled targets under proper hybridization conditions. FIG. 4D illustrates the case wherein maximum hybridization temperature is exceeded and no hybridization takes place.

DETAILED DESCRIPTION OF THE INVENTION

Before describing the present invention in detail, it is to be understood that this invention is not limited to specific molecular probes, indicator materials, or device structures, as such may vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

It must be noted that, as used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a probe" includes not only a single probe but also a plurality of probes that may be the same or different, reference to "an array" includes a single array as well as a plurality of arrays, reference to "a biomolecule" includes a single biomolecule as well as a combination or mixture of biomolecules that may be the same or different, "a moiety" can refer to a plurality of moieties, and the like.

In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set out below.

The term "adsorb" as used herein refers to the noncovalent retention of a molecule by a substrate surface. That is, adsorption occurs as a result of noncovalent interaction between a substrate surface and adsorbing moieties present on the molecule that is adsorbed. Adsorption may occur through hydrogen bonding, van der Waal's forces, polar attraction or electrostatic forces (i.e., through ionic bonding). Examples of adsorbing moieties include, but are not limited to, amine groups, carboxylic acid moieties, hydroxyl groups, nitroso groups, sulfones and the like. Often the substrate may be functionalized with adsorbent moieties to interact in a certain manner, as when the surface is functionalized with amino groups to render it positively charged in a pH neutral aqueous environment. Likewise, adsorbate moieties may be added in some cases to effect adsorption, as when a basic protein is fused with an acidic peptide sequence to render adsorbate moieties that can interact electrostatically with a positively charged adsorbent moiety.

The term "array" used herein refers to a two-dimensional arrangement of features such as an arrangement of reservoirs (e.g., wells in a well plate) or an arrangement of different materials including ionic, metallic or covalent crystalline, including molecular crystalline, composite or ceramic, glassine, amorphous, fluidic or molecular materials on a substrate surface (as in an oligonucleotide or peptidic array). Different materials in the context of molecular materials includes chemical isomers, including constitutional, geometric and stereoisomers, and in the context of polymeric molecules constitutional isomers having different monomer sequences. Arrays are generally comprised of regular, ordered features, as in, for example, a rectilinear grid, parallel stripes, spirals, and the like, but non-ordered arrays may be advantageously used as well. An array is distinguished from the more general term "pattern" in that patterns do not necessarily contain regular and ordered features. The arrays or patterns formed using the devices and methods of the invention have no optical significance to the unaided human eye. For example, the invention does not involve ink printing on paper or other substrates in order to form letters, numbers, bar codes, figures, or other inscriptions that have optical significance to the unaided human eye. In addition, arrays and patterns formed by the deposition of ejected droplets on a surface as provided herein are preferably substantially

invisible to the unaided human eye. The arrays prepared using the method of the invention generally comprise in the range of about 4 to about 10,000,000 features, more typically about 4 to about 1,000,000 features.

The meaning of the term "attached," as in, for example, a substrate surface having a molecular moiety "attached" thereto (e.g., in the individual molecular moieties in arrays generated using the methodology of the invention), includes covalent binding, adsorption, and physical immobilization. The terms "binding" and "bound" are identical in meaning to the term "attached."

The terms "biomolecule" and "biological molecule" are used interchangeably herein to refer to any organic molecule, whether naturally occurring, recombinantly produced, or chemically synthesized in whole or in part, that is, was or can be a part of a living organism. The terms encompass, for example, nucleotides, amino acids and monosaccharides, as well as oligomeric and polymeric species such as oligonucleotides and polynucleotides, peptidic molecules such as oligopeptides, polypeptides and proteins, saccharides such as disaccharides, oligosaccharides, polysaccharides, mucopolysaccharides or peptidoglycans (peptido-polysaccharides) and the like. The term also encompasses ribosomes, enzyme cofactors, pharmacologically active agents, and the like.

The term "biomaterial" refers to any material that is biocompatible, i.e., compatible with a biological system comprised of biological molecules as defined above.

The terms "library" and "combinatorial library" are used interchangeably herein to refer to a plurality of chemical or biological moieties present on the surface of a substrate, wherein each moiety is different from each other moiety. The moieties may be, e.g., peptidic molecules and/or oligonucleotides.

The term "moiety" refers to any particular composition of matter, e.g., a molecular fragment, an intact molecule (including a monomeric molecule, an oligomeric molecule, and a polymer), or a mixture of materials (for example, an alloy or a laminate).

It will be appreciated that, as used herein, the terms "nucleoside" and "nucleotide" refer to nucleosides and nucleotides containing not only the conventional purine and pyrimidine bases, i.e., adenine (A), thymine (T), cytosine (C), guanine (G) and uracil (U),

but also protected forms thereof, e.g., wherein the base is protected with a protecting group such as acetyl, difluoroacetyl, trifluoroacetyl, isobutyryl or benzoyl, and purine and pyrimidine analogs. Suitable analogs will be known to those skilled in the art and are described in the pertinent texts and literature. Common analogs include, but are not limited to, 1-methyladenine, 2-methyladenine, N^6-methyladenine, N^6-isopentyladenine, 2-methylthio-N^6-isopentyladenine, N,N-dimethyladenine, 8-bromoadenine, 2-thiocytosine, 3-methylcytosine, 5-methylcytosine, 5-ethylcytosine, 4-acetylcytosine, 1-methylguanine, 2-methylguanine, 7-methylguanine, 2,2-dimethylguanine, 8-bromoguanine, 8-chloroguanine, 8-aminoguanine, 8-methylguanine, 8-thioguanine, 5-fluorouracil, 5-bromouracil, 5-chlorouracil, 5-iodouracil, 5-ethyluracil, 5-propyluracil, 5-methoxyuracil, 5-hydroxymethyluracil, 5-(carboxyhydroxymethyl)uracil, 5-(methylaminomethyl)uracil, 5-(carboxymethylaminomethyl)-uracil, 2-thiouracil, 5-methyl-2-thiouracil, 5-(2-bromovinyl)uracil, uracil-5-oxyacetic acid, uracil-5-oxyacetic acid methyl ester, pseudouracil, 1-methylpseudouracil, queosine, inosine, 1-methylinosine, hypoxanthine, xanthine, 2-aminopurine, 6-hydroxyaminopurine, 6-thiopurine and 2,6-diaminopurine. In addition, the terms "nucleoside" and "nucleotide" include those moieties that contain not only conventional ribose and deoxyribose sugars, but other sugars as well. Modified nucleosides or nucleotides also include modifications on the sugar moiety, e.g., wherein one or more of the hydroxyl groups are replaced with halogen atoms or aliphatic groups, or are functionalized as ethers, amines, or the like.

As used herein, the term "oligonucleotide" shall be generic to polydeoxy-nucleotides (containing 2-deoxy-D-ribose), to polyribonucleotides (containing D-ribose), to any other type of polynucleotide that is an N-glycoside of a purine or pyrimidine base, and to other polymers containing nonnucleotidic backbones (for example PNAs), providing that the polymers contain nucleobases in a configuration that allows for base pairing and base stacking, such as is found in DNA and RNA. Thus, these terms include known types of oligonucleotide modifications, for example, substitution of one or more of the naturally occurring nucleotides with an analog, internucleotide modifications such as, for example, those with uncharged linkages (e.g., methyl phosphonates, phospho-triesters, phosphoramidates, carbamates, etc.), with negatively charged linkages (e.g.,

phosphorothioates, phosphorodithioates, etc.), and with positively charged linkages (e.g., aminoalklyphosphoramidates, aminoalkylphosphotriesters), those containing pendant moieties, such as, for example, proteins (including nucleases, toxins, antibodies, signal peptides, poly-L-lysine, etc.), those with intercalators (e.g., acridine, psoralen, etc.), those containing chelators (e.g., metals, radioactive metals, boron, oxidative metals, etc.). There is no intended distinction in length between the terms "polynucleotide" and "oligonucleotide," and these terms will be used interchangeably. These terms refer only to the primary structure of the molecule. As used herein the symbols for nucleotides and polynucleotides are according to the IUPAC-IUB Commission of Biochemical Nomenclature recommendations (*Biochemistry* 9:4022, 1970).

The terms "peptide," "peptidyl" and "peptidic" as used throughout the specification and claims are intended to include any structure comprised of two or more amino acids. For the most part, the peptides in the present arrays comprise about 5 to 10,000 amino acids, preferably about 5 to 1000 amino acids. The amino acids forming all or a part of a peptide may be any of the twenty conventional, naturally occurring amino acids, i.e., alanine (A), cysteine (C), aspartic acid (D), glutamic acid (E), phenylalanine (F), glycine (G), histidine (H), isoleucine (I), lysine (K), leucine (L), methionine (M), asparagine (N), proline (P), glutamine (Q), arginine (R), serine (S), threonine (T), valine (V), tryptophan (W), and tyrosine (Y). Any of the amino acids in the peptidic molecules forming the present arrays may be replaced by a non-conventional amino acid. In general, conservative replacements are preferred. Conservative replacements substitute the original amino acid with a non-conventional amino acid that resembles the original in one or more of its characteristic properties (e.g., charge, hydrophobicity, stearic bulk; for example, one may replace Val with Nval). The term "non-conventional amino acid" refers to amino acids other than conventional amino acids, and include, for example, isomers and modifications of the conventional amino acids (e.g., D-amino acids), non-protein amino acids, post-translationally modified amino acids, enzymatically modified amino acids, constructs or structures designed to mimic amino acids (e.g., α,α-disubstituted amino acids, N-alkyl amino acids, lactic acid, β-alanine, naphthylalanine, 3-pyridylalanine, 4-hydroxyproline, O-phosphoserine,

N-acetylserine, N-formylmethionine, 3-methylhistidine, 5-hydroxylysine, and norleucine), and peptides having the naturally occurring amide -CONH- linkage replaced at one or more sites within the peptide backbone with a non-conventional linkage such as N-substituted amide, ester, thioamide, retropeptide (-NHCO-), retrothioamide (-NHCS-), sulfonamido ($-SO_2NH-$), and/or peptoid (N-substituted glycine) linkages. Accordingly, the peptidic molecules of the array include pseudopeptides and peptidomimetics. The peptides of this invention can be (a) naturally occurring, (b) produced by chemical synthesis, (c) produced by recombinant DNA technology, (d) produced by biochemical or enzymatic fragmentation of larger molecules, (e) produced by methods resulting from a combination of methods (a) through (d) listed above, or (f) produced by any other means for producing peptides.

The term "fluid" as used herein refers to matter that is nonsolid or at least partially gaseous and/or liquid. A fluid may contain a solid that is minimally, partially or fully solvated, dispersed or suspended. Examples of fluids include, without limitation, aqueous liquids (including water *per se* and salt water) and nonaqueous liquids such as organic solvents and the like.

The term "discrete" is used herein in the ordinary sense to refer to a region of a substrate that constitutes a separate or distinct part with respect to another region of the substrate. Thus, one discrete region of a substrate such as the interior region is readily distinguishable from another region such as the surface.

The term "hybridizing conditions" is intended to mean those conditions of time, temperature, and pH, and the necessary amounts and concentrations of molecular moieties and reagents, sufficient to allow at least a portion of a nucleotidic moiety to anneal with its complementary sequence. As is well known in the art, the time, temperature, and pH conditions required to accomplish hybridization depend on the size or length of the oligonucleotide moiety to be hybridized, the degree of complementarity between the oligonucleotide probe and target, the presence of secondary structure in the probe and the target, and the presence of other materials in the hybridization reaction admixture. The actual conditions necessary for each hybridization step are well known in the art or can be determined without undue experimentation.

"Optional" or "optionally" means that the subsequently described circumstance may or may not occur, so that the description includes instances where the circumstance occurs and instances where it does not.

The term "probe" as used herein refers to a molecular moiety that exhibits a reaction in response to the presence of a "target." Typically, the probes and targets are complementary to each other chemically so as to exhibit a "target-probe interaction." Examples of target-probe interactions include hybridization reactions between nucleotidic moieties and antibody-binding reactions such as that exhibited when an antibody reacts with a particular protein or when an epitope reacts with a portion of a particular protein. Thus, two targets may represent different portions of a single molecule. For example, two different nucleotidic targets may represent two different sequenced portions of a single polynucleotide. In addition, probes are typically bound to a substrate while targets, if they are present in a fluid sample, are substantially suspended in the fluid sample.

The term "substrate" as used herein refers to any material having a surface onto which one or more fluids may be deposited. The substrate may be constructed in any of a number of forms such as wafers, slides, well plates, membranes, for example. In addition, the substrate may be porous or nonporous as may be required for deposition of a particular fluid. Suitable substrate materials include, but are not limited to, supports that are typically used for solid phase chemical synthesis, e.g., polymeric materials (e.g., polystyrene, polyvinyl acetate, polyvinyl chloride, polyvinyl pyrrolidone, polyacrylonitrile, polyacrylamide, polymethyl methacrylate, polytetrafluoroethylene, polyethylene, polypropylene, polyvinylidene fluoride, polycarbonate, divinylbenzene styrene-based polymers), agarose (e.g., Sepharose®), dextran (e.g., Sephadex®), cellulosic polymers and other polysaccharides, silica and silica-based materials, glass (particularly controlled pore glass, or "CPG") and functionalized glasses, ceramics, and such substrates treated with surface coatings, e.g., with microporous polymers (particularly cellulosic polymers such as nitrocellulose), microporous metallic compounds (particularly microporous aluminum), antibody-binding proteins (available from Pierce Chemical Co., Rockford IL), bisphenol A polycarbonate, or the like.

Substrates of particular interest are porous, and include, as alluded to above: uncoated porous glass slides, including CPG slides; porous glass slides coated with a polymeric coating, e.g., an aminosilane or poly-L-lysine coating, thus having a porous polymeric surface; and nonporous glass slides coated with a porous coating. The porous coating may be a porous polymer coating, such as may be comprised of a cellulosic polymer (e.g., nitrocellulose) or polyacrylamide, or a porous metallic coating (for example, comprised of microporous aluminum). Examples of commercially available substrates having porous surfaces include the Fluorescent Array Surface Technology (FAST™) slides available from Schleicher & Schuell, Inc. (Keene, NH), which are coated with a 10-30 μm thick porous, fluid-permeable nitrocellulose layer that substantially increases the available binding area per unit area of surface. Other commercially available porous substrates include the CREATIVECHIP® permeable slides currently available from Eppendorf AG (Hamburg, Germany), and substrates having "three-dimensional" geometry, by virtue of an ordered, highly porous structure that enables reagents to flow into and penetrate through the pores and channels of the entire structure. Such substrates are available from Gene Logic, Inc. under the tradename "Flow-Thru Chip," and are described by Steel et al. in Chapter 5 of *Microarray Biochip Technology* (BioTechniques Books, Natick, MA, 2000).

The term "porous" as in a "porous substrate" or a "substrate having a porous surface," refers to a substrate or surface, respectively, having a porosity (void percentage) in the range of about 1% to about 99%, preferably about 5% to about 99%, more preferably in the range of about 15% to about 95%, and an average pore size of about 100 Å to about 1 mm, typically about 500 Å to about 0.5 mm.

The term "impermeable" is used in the conventional sense to mean not permitting water or other fluid to pass through. The term "permeable" as used herein means not "impermeable." Thus, a "permeable substrate" and a "substrate having a permeable surface" refer to a substrate or surface, respectively, which can be permeated with water or other fluid.

While the foregoing support materials are representative of conventionally used substrates, it is to be understood that a substrate may in fact comprise any biological,

nonbiological, organic and/or inorganic material, and may be in any of a variety of physical forms, e.g., particles, strands, precipitates, gels, sheets, tubing, spheres, containers, capillaries, pads, slices, films, plates, and the like, and may further have any desired shape, such as a disc, square, sphere, circle, etc. The substrate surface may or may not be flat, e.g., the surface may contain raised or depressed regions. A substrate may additionally contain or be derivatized to contain reactive functionalities that covalently link a compound to the substrate surface. These are widely known and include, for example, silicon dioxide supports containing reactive Si-OH groups, polyacrylamide supports, polystyrene supports, polyethylene glycol supports, and the like.

The term "surface modification" as used herein refers to the chemical and/or physical alteration of a surface by an additive or subtractive process to change one or more chemical and/or physical properties of a substrate surface or a selected site or region of a substrate surface. For example, surface modification may involve (1) changing the wetting properties of a surface, (2) functionalizing a surface, i.e., providing, modifying or substituting surface functional groups, (3) defunctionalizing a surface, i.e., removing surface functional groups, (4) otherwise altering the chemical composition of a surface, e.g., through etching, (5) increasing or decreasing surface roughness, (6) providing a coating on a surface, e.g., a coating that exhibits wetting properties that are different from the wetting properties of the surface, and/or (7) depositing particulates on a surface.

"Optional" or "optionally" means that the subsequently described circumstance may or may not occur, so that the description includes instances where the circumstance occurs and instances where it does not.

The term "substantially" as in, for example, the phrase "substantially all molecules of an array," refers to at least 90%, preferably at least 95%, more preferably at least 99%, and most preferably at least 99.9%, of the molecules of an array. Other uses of the term "substantially" involve an analogous definition.

Overall, the present invention involves devices having at least one indicator to record conditions to which the device has been exposed. The devices are typically used in molecular or biomolecular assays wherein probes of the device interact with targets that may be present in a sample, and the indicators provide a record of the assay conditions. The record of the assay conditions provides users of the inventive device information useful in assay result analysis. That is, if probe-target interactions are observed, the record of the assay conditions is useful in interpreting the significance of such interactions.

In one embodiment, the invention pertains to a device comprising a substrate having a plurality of different molecular probes attached to a surface thereof and an integrated indicator that exhibits a response when exposed to a condition to which the substrate may be exposed. Each of the different molecular probes is selected to interact with a different corresponding target, and the indicator response is detectable after the indicator is removed from the condition. Typically, the indicator response to the condition is detectable for at least one minute after removing the indicator from the condition. The indicator response is preferably detectable for at least one hour, and, optimally, the indicator response is substantially and permanently detectable after removing the substrate from the condition.

The indicator may be responsive to a condition that facilitates, enhances, hinders, or prevents target-probe interaction. For example, the condition may be an environmental condition that may or may not be predetermined to affect target-probe interaction. Such an environmental condition may be a maximum temperature, a minimum temperature, or a temperature range. Other examples of environmental conditions include, but are not limited to, water content, chemical content, and chemical concentration. The indicator response may be optically, magnetically, and/or electrically detectable, optionally by a machine. The response may occur after exposure of the indicator to the condition for at least a predetermined period. A predetermined period is typically about one minute to about 48 hours, preferably under 24 hours, e.g., about five to about ten hours and optimally about six to about eight hours.

The molecular probes may be comprised of any chemical moiety that allows interaction with a corresponding target. For example, when the targets are biomolecular, it is preferred that the molecular probes are biomolecular as well. Such probes may be nucleotidic, peptidic, oligomeric, or polymeric. The targets may be single molecules, portions of a single molecule, or portions of a single cell. In addition, it is preferred that the molecular probes be arranged in an array on the substrate surface. Irrespective of whether the probes are arranged in an array, the arrangement should comprise at least about ten probes per square centimeter of substrate surface. Typically, at least about 50,000 probes are attached per square centimeter of surface. More preferably, at least about 200,000 probes/cm^2 are attached. Optimally, the substrate has attached thereto at least 1,000,000 probes/cm^2. Such probes may be attached or synthesized using acoustic ejection. While it is difficult with current technology to produce a substrate having a probe density of greater than about 2,000,000 probes/cm^2, it is envisioned that future probe densities will be limited predominantly by the size of the probes rather than production technology.

The substrate of the device may take a number of forms. For example, the substrate may comprise a disk, tape, well plate, slide, or other object commonly used as a substrate. Optionally, the substrate may further contain machine-readable information and/or a medium on which information may be written. Such a medium is typically selected to contain electronic information and may be noncoplanar with respect to the surface on which the molecular probes are attached. Optimally, the medium is writable from a surface that opposes the surface on which the molecular probes are attached. Devices comprising a substrate having molecular moieties attached to a surface thereof and containing machine-readable information are described in U.S. Patent Applications Serial Nos. 09/712,818 and 09/993,353, ("Integrated Device with Surface-Attached Molecular Moieties and Related Machine-Readable Information"), inventors Ellson, Foote, and Mutz, filed on November 13, 2000 and November 13, 2001, respectively, and assigned to Picoliter Inc. (Mountain View, California).

FIG. 1 schematically illustrates an example of the above-described embodiment wherein the substrate is in the form of a disk, specifically a compact disk. As with all

figures referenced herein, in which like parts are referenced by like numerals, FIG. 1 is not necessarily to scale, and certain dimensions may be exaggerated for clarity of presentation. The device **11** is comprised of a solid circular disk **13** having opposing and substantially parallel surfaces, indicated at **15** and **17**, respectively. Located at the center of the disk is a circular hole **19** extending through the disk. Attached to exterior surface **15** is a plurality of different molecular probes **21** in the form of an array. That is, the molecular probes **21** represent features of the array, with the features forming concentric circles about the center hole **19** of the disk. As such, the disk is substantially symmetric about its center and is thus substantially rotationally uniform. Preferably, the radial mass distribution of the disk is also substantially uniform. Other distributions of probes are possible provided that the mass distribution does not substantially interfere with the rotational stability of the disk. Rotational stability depends on mass distribution, rate of rotation, and other parameters for disk and rotational means design known in the art. Each of the different molecular probes **21** is selected to interact with a different corresponding target. Thus, by determining which probes exhibit evidence of a response from interaction with a target, a sample that may contain targets may be assayed.

Also shown on surface **15** is an integrated indicator **20** that exhibits a response after exposure to a condition to which the disk **13** may be exposed. The indicator response, if triggered, indicates whether the disk has been exposed to the condition. Thus, the presence or absence of the indicator response may be used as a quality control measure to assess the accuracy and/or reliability of the assay. Because the integrated indicator is on the same surface as the molecular probes **21**, a detector for detecting probe-target interaction may also be adapted to detect the indicator response as discussed below. In addition, when the substrate is symmetrical, axial or otherwise, it is useful to establish the orientation of the substrate with respect to the detector. Thus, either or both of surfaces **15** and **17** may be marked to establish orientation. For example, a reference molecular moiety may be used to establish a reference point on the surface to which the probes are attached. As shown, the integrated indicator **20** itself serves as such a reference point.

Optionally, the disk contains a medium on which information may be written. Typically, such a medium is contained in a discrete portion of the device. As shown, the medium is contained in the disk **13** as a spiral track **23**. One way in which information may be written on the medium is to encode data as a series of reflective features and non-reflective pits. In such a case, the information is optically readable by rotating the disk **13** about the center hole **19** and providing an optical reader adapted to read the information from the underside **17** of the disk **13**. Design and construction of such optical readers are well known in the art. As the information is located within the disk as a spiral track **23** rather than on the surface **15** to which the molecular probes **21** are attached, it is evident that the information is located in a discrete region of the disk that is noncoplanar with respect to surface **15** on which the molecular probes **21** are attached. In this case, it is desirable to ensure a spatial correspondence between the information contained in the disk and the probes attached to the disk. Thus, the integrated indicator **20** may be located at the nearest point on surface **15** to the location of the end **22** of the spiral track **23.** This allows the reading of machine-readable information to act as a positional encoder for properly depositing the moieties on the opposing surface. In other words, the act of reading the machine-readable information from the spiral track **23** on surface **17** could determine the rotational position of the disk **13**. This correspondence may be used to improve the timing of release of materials by a deposition system adapted for controlled delivery of materials to the substrate.

In another embodiment, the invention pertains to a device comprising a substrate having a plurality of molecular probes attached to a surface thereof and a plurality of different integrated indicators. Each indicator is selected to exhibit a response when exposed to one of a plurality of conditions to which the substrate may be exposed. The molecular probes are selected to interact with corresponding targets. The indicator response is detectable after removing the indicator from the condition.

This embodiment is similar to the above-described embodiment in that it provides for an indicator response to a condition, wherein the response is detectable as described above. The molecular probes of this embodiment and the arrangement thereof are also as described above. Furthermore, the substrate of this embodiment may also generally take

the forms of the previously described embodiment. This embodiment, however, provides for a greater amount of information relating to the exposure of device and associated probes to various conditions. Such additional information may in turn ensure the accuracy of assays carried out using the probes of the substrate. For example, the molecular probes of this embodiment may be selected to interact with corresponding targets when exposed to at least one of the plurality of conditions. Alternatively, the molecular probes may be selected to interact with corresponding targets when exposed to all of the conditions. Optimally, the molecular probes may be selected to interact with corresponding targets when exposed to all of the conditions simultaneously

FIG. 2 schematically illustrates an example of the above-described embodiment wherein the substrate is in the form of a well plate. The device **11** is comprised of a well plate **13** having individual wells **27** terminating at openings in an exterior surface **16** and arranged in an array. Such well plates are commercially available from Corning Inc. (Corning, New York) and Greiner America, Inc. (Lake Mary, Florida). As shown, each individual well **27** has a molecular probe **21** bound to an interior surface **15** thereof. However, the probe is not necessarily covalently bound to the plate. For example, the probe may be in solution. As a general rule, though, if an array of probes is located in an interior surface of the well, each probe is bound to the surface.

In addition, an array of integrated indicators **20** is also provided on the exterior surface of the well plate **13**. As shown, the indicators **20** are placed in a row on a portion of the exterior surface **16**. As described above, these indicators **20** exhibit a response after exposure to a condition to which the well plate **13** may be exposed. These indicators may each indicate a different condition, or some may indicate the same condition. For example, the indicators may each indicate a different temperature and be arranged in order of increasing temperature in the direction indicated by arrow **D**. In the alternative, any two of the indicators may be provided to indicate the same condition to ensure that each indicator has an auxiliary in case of failure. Due to the proximity of the indicators to the moieties, the indicators experience similar conditions to those experienced by the probes. As a result, the conditions indicated by the indicators closely approximate those experienced by the probes.

Optionally, the well plate **13** is attached to a cartridge base **29** to define a cartridge interior **31**. A magnetic disk **33** is generally interposed between well plate **13** and the cartridge base **29** within the cartridge interior **31.** The disk **33** is a generally flat and circular piece having an upper surface **35** and a lower surface **37**. A cylindrical hub **39** extends perpendicularly from the center of the lower surface **37** of the disk **33** through a circular opening **41** of the cartridge base **29**. The disk is free to rotate about its hub in a generally free-floating manner. The lower surface **37** is coated with a magnetic storage medium **43** that allows a spiral track **23** to be formed therein to magnetically store machine-readable information related to the molecular probes. Also optionally located in the cartridge base **29** is a rectangular opening **45** that provides external access to the magnetic disk contained in the cartridge interior **31**. A slidable spring-loaded panel **47** covers the opening **45** in order to protect the magnetic medium on the disk from damage when the disk is not in use. As shown, the slidable panel **47** is positioned such that it does not cover the opening, thereby providing a magnetic reader access to the magnetic medium on the disk. Thus, the information contained in the spiral track **23** is ready for reading by a magnetic reader. Design, construction, and use of such magnetic readers are well known in the art. For example, the magnetic reader may engage the disk by gripping the portion of the hub **39** that is accessible to the exterior to the cartridge and spinning the disk. This allows information contained in the spiral track to be read. As the information relating to the attached probes is located within the disk as a spiral track **23** rather than on the interior surfaces **15** of the well plate to which the molecular probes **21** are attached, it is evident that the information is located in a discrete region of the disk that is noncoplanar with respect to the surfaces **15**. Optionally, one or more of the interior surfaces **15** may be covered with a protective layer (not shown) that protects the probes from damage as a result of improper handling. Devices for sealing well plates are commercially available from many sources including TekCel Corporation (Hopkinton, MA). Such protective coatings may also be adapted to protect the integrated indicators.

In still another embodiment, the invention pertains to a device comprising a substrate having a plurality of nucleotidic molecular probes attached to a surface thereof and an integrated indicator that exhibits a response when exposed to a condition to which

the substrate may be exposed. The nucleotidic molecular probes are selected to interact with corresponding targets. This embodiment also provides for an indicator response to a condition wherein the response is detectable as described above. The nucleotidic molecular probes of this embodiment and the arrangement thereof are also described above. Furthermore, the substrate of this embodiment may also take the forms of the previously described embodiment. This embodiment, however, provides a device that is especially useful in determining the nucleotidic content of a sample when the condition represents a hybridization condition between the probes and targets.

For example, the nucleotidic molecular probes of this embodiment may be selected to interact with corresponding targets when exposed to at least one of the plurality of conditions. Alternatively, the molecular probes may be selected to interact with corresponding targets when exposed to all of the conditions. Optimally, the molecular probes may be selected to interact with corresponding targets when exposed to all of the conditions simultaneously.

FIG. 3 schematically illustrates in simplified cross-sectional view another version of the inventive device. This version uses an ordinary microscope slide as the substrate. The device **11** is comprised of a rectangular slide **13** having opposing and substantially parallel surfaces, indicated at **15** and **17**. The slide may be formed in any convenient size, but is preferably a solid support such as a standardized glass microscope slide that has a rectangular surface of about 3 inches by 1 inch (75 mm × 25mm). Optionally, the slide may have coatings of substantially uniform thickness applied to various portions of its surface to form a raised exterior surface to improve the attachment of probes or indicators. Attached to exterior surface **15** is a plurality of nucleotidic molecular probes **21** in the form of an array. That is, the nucleotidic molecular probes **21** represent individual features of the array, with the features forming a preferably rectilinear array such that each feature has four equidistant nearest neighbors.

While only one indicator is required for this embodiment, an array of integrated indicators **20** is shown provided on exterior surface **15** of the slide **13**. As shown, the indicators **20** are also placed in a rectilinear array, wherein each indicator is located adjacent to a probe. That is, the indicators are uniformly interspersed among the

nucleotidic molecular probes. As discussed above, these indicators exhibit a response after exposure to a condition to which the slide may be exposed. Interspersion among the probes allows the indicators to be exposed to substantially the same conditions as the nucleotide probes. As such, if a sample is applied to the probes for assaying the nucleotidic content of the sample, the indicators should provide an accurate measure of whether the hybridization conditions are met.

Optionally, information relating to the molecular probes is contained in an electronic microchip **23** that provides sufficient memory to store such information. As shown, the microchip **23** is embedded in the slide **13**. Such a microchip **23** may be partially exposed at surface **17**, as shown in FIG. 3, or be located entirely within the substrate. Such microchips are often employed in smart cards, e.g., plastic cards resembling a credit card that contains a computer chip, which enables various operations to be performed, such as mathematical calculations, paying of bills, and the purchasing of goods and services. Use of smart card technology in conjunction with nucleotidic probes is described in U.S. Patent Applications Serial Nos. 09/712,818 and 09/993,353, referenced *supra*.

As discussed above, any of the indicators for use in the invention may be responsive to various predetermined or other conditions such as conditions that facilitate, enhance, hinder, or prevent target-probe interaction. Thus, the indicator should be selected to exhibit a response that indicates with sufficient accuracy and precision whether target-probe interaction conditions are met. Preferably, the response is sufficiently similar to the target-probe interaction signal such that both can be detected using the same detection means.

Various types of indicators and detectable responses are also useful in conjunction with the invention, as will be appreciated by those skilled in the art. The response may be directly detectable, as with fluorescent, chemiluminescent, radioactive and electrochemical indicators, or it may be indirectly detectable, such as with biotin or another ligand or hapten. With indirectly detectable indicators, a further reaction is utilized to provide a measurable signature. The further reaction may include reaction with a conjugate label containing a specific binding partner for the hapten and a suitable

directly detectable label. Fluorescence is often used to detect nucleotidic probe-target interactions (such as hybridization) using fluorescence readers, such as the GenePix 4000 from Axon Instruments, Inc. (Foster City, California). Condition indicators employed in hybridization arrays may therefore also exhibit fluorescent responses to hybridization. Typically, the response will involve fluorescence emission, as will be seen with fluorescent dyes, e.g., fluorescein dyes such as fluorescein *per se*, fluorescein isothiocyanate, 6-carboxyfluorescein (6-FAM), 2',4',1,4,-tetrachlorofluorescein (TET), 2',4',5',7',1,4-hexachlorofluorescein (HEX), 2',7'-dimethoxy-4',5'-dichloro-6-carboxyrhodarnine (JOE), 2'-chloro-5'-fluoro-7',8'-fused phenyl-1,4-dichloro-6-carboxyfluorescein (NED), and 2'-chloro-7'-phenyl-1,4-dichloro-6-carboxyfluorescein (VIC). However, the response may also involve fluorescence quenching, as when an oligonucleotide labeled with a fluorescence quencher hybridizes to an oligonucleotide labeled with a fluorescent moiety. Fluorescer-quencher pairs include, by way of example, (1) a fluorescein dye with any one of sulforhodamine 101, sulfonyl chloride (Texas Red), succinimdyl 1-pyrenebutyrate, tetramethylrhodamine (TMR), tetramethylrhodamine isothiocyanate (TRITC), eosin-5-isothiocyanate (EITC), and erythrosine-5-isothiocyanate; coumarin dyes such as 7-amino-4-methylcoumarin-3-acetic acid, N-hydroxysuccinimidyl ester with either 4-dimethylaminophenylazo)benzoic acid, N-hydroxysuccinimidyl ester ("DABCYL NHS-ester") or 4-dimethylaminoazobenzene sulfonyl chloride ("DABSYL" chloride).

As alluded to above, the response may also be detected as particle emission radiation, as will be the case with a radioisotopic indicator such as ^{32}P or tritium. The indicator may also be an ionized moiety, or a moiety that ionizes under certain conditions, in which case the response will be electrochemically detectable. More preferably, the response will be optically detectable, as will be the case with a fluorescent dye, or a fluorescent dye-fluorescence quencher pair, and with a chemiluminescent indicator such as acridine, luminol, or quinoline. If desired, one may use the method of the invention with only a single indicator, which serves both to provide the target-probe response and to indicate a condition to which the substrate may be exposed.

An important environmental condition for hybridization as well as other biomolecular assays is temperature. Various temperature indicators are known in the art that respond to temperature variations through dimensional and/or chromatic changes. For example, wax shapes having specific melting points can be used to indicate temperatures to which the shapes have been exposed. In addition, when nucleotidic or other types of probes are employed in the inventive device, nucleotidic indicators may also be employed to indicate temperatures to which the substrate has been exposed. For example, it is known that double-stranded DNA dissociates to single strands at a temperature that depends on its nucleotide content. It is also known that G-C base pairs are bound by three hydrogen bonds and hence dissociate at a higher temperature than A-T base pairs, which employ two hydrogen bonds. The temperature at which a particular sample of DNA is 50% dissociated into single strands is known as its melting temperature (T_m). T_m is very sensitive to the specific sequences of associating DNA pairs. It should be evident from the above disclosure that this phenomenon may be exploited to produce nucleotidic temperature indicators having a predetermined T_m. In order to ensure that the indicators exhibit a specific T_m, one may produce such nucleotidic temperature indicators by controlling the composition, sequence, and length of the oligonucleotides or polynucleotides that form the indicators.

For example, one or more nucleotidic features may be used as temperature indicators in the present invention. Such features may contain either single-stranded oligonucleotides having defined sequences prehybridized to a labeled target, or double-stranded oligonucleotides having one labeled strand. In either case, the non-labeled strand is attached to the substrate. Typically, the attached strand is longer than the labeled strand, leaving the shorter, labeled strand free to dissociate from the long strand when T_m is reached. Thus, when the inventive device is subjected to an assay temperature, the labeled strand of the nucleotidic indicators having a T_m lower than the assay temperature would be released through melting, while those indicators having a T_m higher than the assay temperature would retain the labeled strand. Accordingly, identifying the indicators that have melted and their associated T_m values can determine the assay temperature.

It is important to ensure that melting does not release labeled strands that subsequently reattach to the device or rehybridize with a portion thereof, thereby resulting in a spurious signal or interfering with experimental data. Thus, employing melting nucleotides to monitor temperature may require providing a wash step to carry away strands released from such melting. In addition, other techniques may be employed to further mitigate such potentially deleterious effects. For example, indicators may be positioned on a discrete portion of the substrate to ensure that released label strands do not come into contact with the probes attached to the substrate. As another example, highly artificial or exotic sequences could also reduce the likelihood of interference with the probes. See, e.g., U.S. Patent Applications Serial Nos. 09/669,267 ("Arrays of Oligonucleotides Containing Nonhybridizing Segments") and 09/962,731 ("Arrays of Partially Nonhybridizing Oligonucleotides and Preparation Thereof Using Focused Acoustic Energy"), inventor Ellson, filed on September 25, 2000 and September 24, 2001, respectively, and assigned to Picoliter Inc. (Mountain View, California). As still another embodiment, a different label may be used with the temperature-indicator nucleotidic material than that employed for the probe. Other ways to reduce such interference may be known in the art as well.

Complementary single-stranded nucleotidic material can be annealed to induce hybridization, and this phenomenon is the basis of all nucleic acid hybridization technology. The kinetics of single strand association is second-order and necessarily more complex than that of dissociation, depending on the relative concentration of the components as well as factors such as degree of sequence repetition, ionic strength, pH, and temperature. Thus, this annealing phenomenon can also be employed to provide an indication of temperature as well as other environmental conditions relating to hybridization, such as pH.

One way in which annealing may be used to measure temperature during a hybridization assay is to employ a series of features as indicators, each feature containing a plurality of single-stranded nucleotidic oligomers. Each feature contains random-sequence oligonucleotidic strands having the same ratio of triple-hydrogen-bond bases to double-hydrogen-bond bases. That is, the ratio of Gs and Cs to As and Ts is the same for

all nucleotidic strands within a feature. When a sample is applied to both device probes and indicator oligonucleotides, a portion of the indicator strands and labeled targets in the sample may bind. For a given assay, hybridization kinetics might be expected to favor features containing oligonucleotides with a T_m above the assay temperature. Therefore, with proper calibration, hybridization would be detected at high T_m features and be absent from low T_m features. A gradient or cutoff of signal intensity could then be used to determine the temperature at which the hybridization was performed.

A potential problem with the above annealing approach is that positional effects and the degree of sequence repetition can also affect hybridization kinetics. Thus, random-sequence strands of a feature may exhibit a range of hybridization rates, even if the triple-hydrogen-bond to double-hydrogen-bond base ratio for the strands is identical. This variability complicates the precise determination of the temperature such that mere observing of hybridization activity of the features may not be sufficient. Instead of using randomly sequenced strands as temperature indicators, another approach is to employ strands having sequences corresponding to well-characterized sequences known to be present in the sample, e.g., sequences associated with a housekeeping gene. This approach tends to increase signal intensity associated with hybridization.

Still another hybridization approach is similar to the above, except that the temperature indicator strands are keyed to calibrant strands incorporated into the sample. It is preferable that the calibrant strands contain highly artificial or exotic sequences to reduce the likelihood of binding with the probes, and thereby interference with the desired target-probe interactions. This approach has the advantage that both temperature-indicator strands and calibrant strands can be carefully controlled to indicate precise assay conditions.

For hybridization assays, the indicator may be employed to indicate a predetermined temperature associated with hybridization. For example, the predetermined temperature may be a maximum hybridization temperature of about 60°C to about 90°C for hybridization. In the alternative, the predetermined temperature may be a minimum hybridization temperature of about 35°C to about 45°C. The precise

predetermined temperature will vary according to the precise nature of the assay. These temperature ranges may be useful for non-hybridization assays as well.

In addition to temperature, there are other environmental conditions that affect hybridization and other biomolecular assays. These conditions include, for example, water content and chemical concentration. Thus, the indicators of the present invention may be chosen to provide a record of these conditions as well. For example, pH sensitive compounds are well known in the art and a number of references disclose their incorporation in substrates. In a preferred embodiment, the indicator is also surface bound and exhibits a fluorescent response to pH. Offenbacher et al. (1986), "Fluorescence Optical Sensors for Continuous Determination of Near Neutral pH Values," *Sensors and Actuators* 9: 73-84, report that glass-immobilized sensors may allow for pH determination in the range of 6.4 to 7.7. That is, a high-sensitivity, fluorescence-based pH probe such as 7-hydroxycoumarin-3-carboxylic acid can be embedded in glass and coupled to surface amines by the commonly used coupling reagent 1-ethyl-3-(3-dimethylaminoproyl)-carbodiimide hydrochloride. Such probes have different protonation states in response to local environmental pH. In addition, these differing protonation states translate into different intensities of emission spectra and can be used to calibrate a pH determination to a standard deviation of about ± 0.01 unit.

To create an effective indicator for ionic strength, one may hydroxylate the glass surface and introduce ionic sensitivity to the fluorescent readout. The presence of hydroxyl groups in the proximity of the fluorescent indicators induces electrostatic interaction between the charged groups, and the surface can then serve as a readout of ionic strength. Ionic strength affects the dissociation constant of weak electrolytes such as 1-hydroxypyrene-3,6,8-trisulfonate or as 7-hydroxycoumarin-3-carboxylic acid according to equation (I):

(I) $$pK_a^{\ I} = pK_a^{\ TH} + (0.512z_B^{\ 2} - z_{HB}^{\ 2})I^{1/2}/(1+1.6I^{1/2})$$

where pK_a^I represents the acid dissociation constant at ionic strength I, pK_a^{TH} is the thermodynamic acid dissociation constant, and z_B and z_{HB} are the charges of the deprotonated and protonated species, respectively. See Wolfbeis et al., (1986) "Fluorescence Sensor for Monitoring Ionic Strength and Physicological pH Values," *Sensors and Actuators* 9:85-91.

As another example, Obnik et al, (1998) "pH Optical Sensors Based on Sol-Gels: Chemical Doping versus Covalent Immobilization," *Analytica Chimica Acta* 367: 159-165, report the use of silica-immobilized aminofluorescein to detect changes in the pH range 4 to 9. Through use of a flow cell, pH changes are reported as changes in fluorescence signal intensity (max emission wavelength varies with conditions) after excitation at 490 nm. Aminofluorescein is described as either covalently bound to, or doped into, a silica sol-gel that, in turn, is fixed onto a glass slide as a thin layer. It is further disclosed that covalent binding provides superior stability, while doping affords an easier and more general synthesis.

As a further example, Wolfbeis et al., (1992) "LED-Compatible Fluorosensor for Measurement of Near-Neutral pH Values," *Mikrochimica Acta* 108:133-141 report that the fluorescent indicator 5-(and 6-)carboxynaphthofluorescein can be immobilized and used in a pH range of 6 to 9. This indicator can be immobilized in two ways, either by covalent attachment to a cellulose matrix, or by mechanical entrapment in a sol-gel glass. The cellulose conjugate can be formed into sensing membranes of approximately 30 micrometers thick, while the sol-gel can be deposited onto glass slides as in the previous reference. Again, detection is carried out in a flow cell. Spectral characteristics varied among various conditions. Interestingly, by using an excitatory wavelength above 500 nm, the sensors are compatible with conventional LEDs. The cellulose formulation is considered superior for constructing a pH sensor, because of the stability of the covalent fluorophore immobilization. It should be apparent, then, that any of these sensors and immobilization techniques could be incorporated into the present invention to form the above-described integrated indicators. Such indicators employed in the present invention typically respond to a pH of about 5 to about 9.

Similarly, salinity indicators, e.g., compounds that are sensitive to sodium and/or chloride, as well as formamide concentration indicators, are also known in the art. Typically salinity indicators of the present invention are responsive to a salinity of about 0.01 molar to about 8 molar. The indicators may be employed to detect the presence or concentration of a chemical moiety that either enhances or hinders target-probe interactions.

It is noted that certain condition indicators, particularly pH-sensitive indicators, exhibit a response when exposed to the condition but revert to their original state soon after removal from the condition. Thus, preferred indicators exhibit substantially irreversible responses rather than reversible responses. If reversible, the response reversal preferably takes an extended amount of time after removal from the condition that triggers the response to allow the response to be recorded in a more permanent form of information, e.g., by writing to an information-storage medium on the device. In short, when the indicator response is reversible, one of ordinary skill in the art will recognize that the response may be converted into a permanent form before complete reversal.

In another embodiment, the invention provides a method for assaying a sample using any of the above devices. The sample is exposed to an assay condition by contacting the molecular probes attached to the substrate surface of the device. Then, the indicator is examined to determine whether the assay condition has triggered the indicator response to the condition. If the indicator response is detected, the probe-target interactions are then assessed.

Depending on the desired probe-target interaction, assays must be adjusted accordingly. For example, for nucleotidic probe-target interactions, it is generally desirable to maintain conditions for hybridization assays by placing the sample and the device in a controlled environment, heating the device while the sample is in contact therewith, and preventing the sample from evaporating. After hybridization but before detection for hybridization, excess sample is typically removed from the device. In the case wherein the indicator is also nucleotidic, detection of the probe-target interaction and of the indicator response is preferably carried out using a single reader. When the inventive device contains a medium on which information may be written, it may be

desirable to record whether the response and/or the probe-target interaction occurred as information contained in the device.

The assay method may be carried out by employing an apparatus for assaying a sample using the inventive device. The apparatus comprises an applicator for applying a sample to the molecular probes and an indicator-response detector for detecting whether any of the indicators of the inventive device exhibit a response. Typically, the apparatus further includes an interaction detector for detecting probe-target interactions. Such an interaction detector may be a known or yet-to-be-developed optical, magnetic, or electric detector. Depending on the type of indicator of the device, the interaction detector may be activated or deactivated when the indicator-response detector detects a response by the indicator. Optimally, the indicator-response also serves as an interaction detector for detecting probe-target interactions.

FIG. 4 illustrates an example of the above-described method and apparatus for assaying a sample using the inventive device similar to that illustrated in FIG. 3. While this example illustrates a nucleotidic assay, it should be evident that one of ordinary skill in the art may modify the inventive method and device of this example to carry out other types of assays, e.g., peptidic and other biomolecular assays. As shown in FIG. 4A, a device **11** is provided that is similar in construction to the device illustrated in FIG. 3, comprising a rectangular slide **13** having opposing and substantially parallel surfaces indicated at **15** and **17**. Attached to exterior surface **15** is a plurality of different nucleotidic molecular probes **21** in the form of an array, each different nucleotidic molecular probe selected to hybridize with a different corresponding nucleotidic target. Also shown on surface **15** is an integrated indicator **20** comprising a number of identical double-stranded oligonucleotides having a T_m equal to the maximum temperature under which the probes **21** will properly hybridize with their corresponding nucleotidic targets. For simplicity, only one double-stranded oligonucleotide is shown, representing the indicator comprising one nucleotidic strand **26** attached to the substrate and one fluorescently labeled nucleotidic strand **28** hybridized with strand **26**.

As shown in FIG. 4B, the device **11** is then loaded into a hybridization chamber **52** of an apparatus **50** for assaying a sample using the inventive device **11**. It is apparent

that the hybridization chamber should produce conditions that are suitable for hybridization, such as providing heat, preventing sample evaporation, and performing other tasks associated with the assay. The chamber is filled from an inlet **54** with a fluid sample **30** that contains fluorescently labeled nucleotidic targets **32** that may or may not hybridize with the probes **21** attached to the slide **13**, thereby submerging the device. As a result, the fluid sample **30** comes into contact with the probes **21**. The chamber is then closed and brought to assay conditions while the apparatus **50** moves the fluid sample **30** and/or device **11** to ensure proper fluid contact with the probes of the device within the chamber **52**. After sufficient time has passed, the fluid is drained from the hybridization chamber **52** through outlet **56**, and an optional wash step is carried out to remove nonhybridized labeled targets from the slide surface **15**. A fluorescence detector **58** of the apparatus **50** is then employed to detect whether the indicator **20** exhibits fluorescence.

When assay conditions are appropriate for hybridization and targets corresponding to the probes are present in the sample, the probes **21** will hybridize with the targets. This is the case shown in FIG. 4C, wherein some probes are shown hybridized with labeled targets. Since assay conditions never exceeded the maximum hybridization temperature of the probes **21**, the two nucleotidic indicator strands **26** and **28** remain hybridized. Thus, the fluorescence detector **58** will detect the presence of fluorescently labeled indicator strand **28** and proceed to detect for the target-probe interactions by detecting for fluorescence at the probes **21.** However, if the assay conditions are such that the assay temperature exceeds T_m, then the fluorescent detector **58** should detect little or no fluorescence at the indicator **20** since the labeled strand **28** has melted away. In such a case, as shown in FIG. 4D, there may be no detectable fluorescence at the probes **21**. In addition, even if fluorescence is detected at the probes, such fluorescence may not indicate hybridization, only the presence of fluorescent labels. Thus, in this case, absence of fluorescence at the indicator indicates assay conditions inappropriate for hybridization. It should be evident that the above-described apparatus or any portion thereof may employ electromechanical and/or computerized components to carry out the desired assay.

In another embodiment, the invention pertains to a device comprising a substrate having a surface adapted for attachment to a plurality of molecular moieties. An integrated indicator is included in the device and exhibits a response when exposed to a condition. The response is detectable after removing the indicator from the condition. Typically, a response indicates whether the substrate has been exposed to a condition that allows for or precludes attaching the plurality of molecular moieties to the substrate surface. This embodiment represents a precursor to the previously described embodiment illustrated in FIGS. 1-3. That is, by attaching a plurality of molecular moieties to the surface adapted for such a purpose, the previously described embodiments may be manifested. This embodiment is particularly useful for ensuring that the molecular moieties are properly attached to the substrate surface.

Attachment of molecular moieties may be accomplished by using an apparatus for attaching molecular moieties to the substrate surface of the inventive device. A preferred apparatus is described in U.S. Patent Applications Serial Nos. 09/699,996 and 09/964,212 ("Acoustic Ejection of Fluids from a Plurality of Reservoirs"), inventors Ellson, Foote and Mutz, filed on September 25, 2000 and September 25, 2001, respectively, and assigned to Picoliter Inc. (Mountain View, California), referred to above. Such an apparatus enables preparation to order of molecular arrays, particularly biomolecular arrays, having array densities allowed by the array-producing technology, such as photolithographic processes, piezoelectric techniques (e.g., using inkjet printing technology), and microspotting. When focused acoustic energy is used, the array densities that may be achieved using the devices and methods of the invention are at least about 50,000 biomolecules per square centimeter of substrate surface, preferably at least about 200,000 per square centimeter of substrate surface. The biomolecular moieties may be, e.g., peptidic molecules and/or oligonucleotides.

Thus, such an apparatus for attaching molecular moieties to the substrate surface of the device as described above may comprise an indicator-response detector for detecting whether the indicator exhibits the response to the condition and a means for attaching a plurality of molecular moieties to the surface of the substrate. The attaching

means may be activated if the indicator-response detector detects the response to the condition that allows for attaching the plurality of molecular moieties to the substrate surface. That is, a plurality of molecular moieties is attached to the substrate surface if the integrated indicator of the device exhibits a response that allows for attachment to the surface. Alternatively, if the occurrence of a response indicates a condition that precludes the attachment of the moieties to the substrate surface, a plurality of molecular moieties may be attached to the substrate surface if the integrated indicator does not exhibit a response to the condition. Various attachment methods are disclosed, e.g., in U.S. Patent Application Serial Nos. 09/699,996 and 09/964,212. It should be noted that such an apparatus may be employed to attach molecular probes as well as indicators to the substrate of the inventive device.

The chemistry employed in synthesizing substrate-bound oligonucleotides in this way will generally involve now-conventional techniques known to those skilled in the art of nucleic acid chemistry and/or described in the pertinent literature and texts. See, for example, *DNA Microarrays: A Practical Approach*, M. Schena, Ed. (Oxford University Press, 1999). That is, the individual coupling reactions are conducted under standard conditions used for the synthesis of oligonucleotides and conventionally employed with automated oligonucleotide synthesizers. Such methodology is described, for example, in D.M. Matteuci et al. (1980) *Tet. Lett.* 521:719, U.S. Patent No. 4,500,707 to Caruthers et al., and U.S. Patent Nos. 5,436,327 and 5,700,637 to Southern et al.

Alternatively, an oligomer may be synthesized prior to attachment to the substrate surface and then "spotted" onto a particular locus on the surface using the methodology of the invention as described in detail above. Again, the oligomer may be an oligonucleotide, an oligopeptide, or any other biomolecular (or nonbiomolecular) oligomer moiety. Preparation of substrate-bound peptidic molecules, e.g., in peptide arrays and protein arrays, is described in co-pending, commonly assigned U.S. Patent Application Serial No. 09/963,173 ("Focused Acoustic Energy in the Preparation of Peptide Arrays"), inventors Mutz and Ellson, filed on September 25, 2001, referenced *supra*. Preparation of substrate-bound oligonucleotides, particularly arrays of oligonucleotides wherein at least one of the oligonucleotides contains partially

nonhybridizing segments, is described in co-pending, commonly assigned U.S. Patent Application Serial No. 09/962,731 ("Arrays of Oligonucleotides Containing Nonhybridizing Segments"), inventor Ellson, filed on September 24, 2001. Attachment of an oligomer to a surface may involve surface modification in order to promote surface-probe adsorption or another type of attachment as discussed in U.S. Patent Applications Serial Nos. 09/712,818 and 09/993,353, filed on November 13, 2000 and November 13, 2001, respectively ("Integrated Device with Surface-Attached Molecular Moieties and Related Machine-Readable Information"), inventors Ellson, Foote, and Mutz, assigned to Picoliter Inc. (Mountain View, California).

Thus, the invention provides advantages previously unknown in microarray technologies. As discussed above, the invention may be used to avoid the problems associated with labeling samples with different colored tags while exhibiting improved performance. In addition, if two substantially identical inventive devices are employed in hybridization assays but at different times and/or locations, the inventive device may be used to determine whether experimental conditions are the same between the assays. Thus, it should be evident that the device may be used to reduce experimental error arising from using different equipment such as hybridization chambers produced by different manufacturers. Moreover, the devices can be used to determine the optimal range of conditions for particular assays. For example, two substantially identical devices indicating exposure to slightly different conditions but both exhibiting optimal assay performance would provide information regarding a range of conditions for optimal assay performance. In the alternative, two substantially identical devices indicating exposure to slightly different conditions but substantially different assay performances would provide information relating to the conditions that would affect assay performance.

It is to be understood that while the invention has been described in conjunction with the preferred specific embodiments thereof, the foregoing description is intended to illustrate and not limit the scope of the invention. Other aspects, advantages, and modifications will be apparent to those skilled in the art to which the invention pertains. All patents, patent applications, journal articles, and other references cited herein are incorporated by reference in their entireties.